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DESCRIPTION

MONOLITHIC CERAMIC ELECTRONIC COMPONENT AND METHOD FOR MAKING THE SAME

Technical Field

The present invention relates to monolithic ceramic electronic components and methods for making the same. More particularly, the invention relates to monolithic ceramic electronic components, such as monolithic inductors, monolithic capacitors, and monolithic LC composite components, and methods for making the same.

Background Art

In conventional noise suppression chip components, in order to ensure high impedance in the wide frequency range so that a noise reduction effect is achieved, for example, a component is fabricated by stacking a high-permeability magnetic layer and a low-permeability magnetic layer with a coil being disposed in each layer, and connecting the coils in series.

As an example of such a component, Patent Document 1 discloses a monolithic inductor having a structure in which a high-permeability magnetic layer and a low-permeability magnetic layer are integrally laminated with a nonmagnetic intermediate layer therebetween. The nonmagnetic intermediate layer prevents interdiffusion between the

material of the high-permeability magnetic layer and the material of the low-permeability magnetic layer, and prevents degradation in the magnetic properties of both magnetic layers.

Furthermore, Patent Document 2 discloses a monolithic LC composite component having a structure in which a capacitor portion and a coil portion are composed of dielectric layers having different dielectric constants, and the dielectric layers having different dielectric constants are integrally laminated.

However, in the case in which a nonmagnetic intermediate layer is used as in the monolithic inductor of Patent Document 1, the bonding strength is weaker compared with the case in which magnetic layers are directly bonded to each other. Furthermore, in order to obtain satisfactory bonding, the magnetic layers and the nonmagnetic intermediate layer must be adjusted to have the same shrinkage rate during firing, which requires troublesome operation and techniques. Furthermore, a new material for the intermediate layer must be prepared, which is one of the factors of increase in manufacturing costs. The monolithic LC composite component of Patent Document 2 also has substantially the same problem.

Patent Document 1: Japanese Unexamined Patent Application Publication No. 9-7835

Patent Document 2: Japanese Unexamined Patent Application Publication No. 6-232005

Disclosure of Invention

Problems to be Solved by the Invention

It is an object of the present invention to provide a monolithic ceramic electronic component which does not require provision of an intermediate layer and in which the dielectric constant and the permeability are less limited, and a method for making the monolithic ceramic electronic component.

Means for Solving the Problems

In order to achieve the object described above, a monolithic ceramic electronic component in accordance with the present invention includes:

(a) a first element portion comprising a laminate of ceramic layers and internal electrodes; and

(b) a second element portion comprising a laminate of ceramic layers and internal electrodes,

(c) wherein at least the first element portion and the second element portion are stacked to form a ceramic laminate, and the porosity of the ceramic layers of the first element portion is different from the porosity of the ceramic layers of the second element portion.

For example, the first element portion contains a first

coil formed by electrically connecting the internal electrodes, the second element portion contains a second coil formed by electrically connecting the internal electrodes, and the first coil and the second coil are electrically connected to form an inductor. Alternatively, the first element portion contains a coil formed by electrically connecting the internal electrodes, the second element portion contains a capacitor in which any two adjacent electrodes are separated by a ceramic layer, the porosity of the ceramic layers of the second element portion is lower than the porosity of the ceramic layers of the first element portion, and the coil and the capacitor are electrically connected to form an LC filter.

If a ceramic layer contains a high proportion of pores, the permeability and the dielectric constant decrease. Therefore, even using the same material, by setting different porosities, it is possible to obtain a first element portion and a second element portion with different permeabilities and different dielectric constants.

Furthermore, a method for making a monolithic ceramic electronic component according to the present invention includes:

(d) stacking ceramic layers and internal electrodes to form a first element portion, stacking ceramic layers and internal electrodes to form a second element portion, and

stacking at least the first element portion and the second element portion to form a ceramic laminate,

(e) wherein the amount of a granular evaporative pore-forming agent incorporated into a ceramic slurry for forming the ceramic layers of the first element portion is set different from the amount of the granular evaporative pore-forming agent incorporated into a ceramic slurry for forming the ceramic layers of the second element portion so that the first element portion and the second element portion have different porosities of ceramic layers.

Either the ceramic slurry for forming the ceramic layers of the first element portion or the ceramic slurry for forming the ceramic layers of the second element portion may not be incorporated with the granular evaporative pore-forming agent.

Advantages

In accordance with the present invention, by setting the porosity of the ceramic layer of the first element portion different from the porosity of the ceramic layer of the second element portion, even if the ceramic layer of the first element portion and the ceramic layer of the second element portion are composed of the same material, it is possible to produce the first element portion and the second element portion having different permeabilities and different dielectric constants. As a result, it is not

necessary to provide an intermediate layer, and it is possible to obtain a monolithic ceramic electronic component with high design freedom with respect to the dielectric constant and the permeability.

Brief Description of the Drawings

Fig. 1 is an assembly view which shows a monolithic ceramic electronic component according to a first embodiment of the present invention.

Fig. 2 is a perspective view which shows an appearance of the monolithic ceramic electronic component shown in Fig. 1.

Fig. 3 is an enlarged cross-sectional view which schematically shows a part of the monolithic ceramic electronic component shown in Fig. 2.

Fig. 4 is a cross-sectional view which schematically shows the monolithic ceramic electronic component shown in Fig. 2.

Fig. 5 is a graph which shows the frequency characteristics of the monolithic ceramic electronic component shown in Fig. 4.

Fig. 6 is an assembly view which shows a monolithic ceramic electronic component according to a third embodiment of the present invention.

Fig. 7 is a cross-sectional view which schematically shows the monolithic ceramic electronic component shown in

Fig. 6.

Best Mode for Carrying Out the Invention

Embodiments of monolithic ceramic electronic components and methods for making the same in accordance with the present invention will be described below with reference to the attached drawings.

(First Embodiment, Figs. 1 to 5)

As shown in Fig. 1, a monolithic inductor 1 includes low-permeability ceramic green sheets 12 for internal layers provided with coil conductive patterns 5 and via-holes 6 for interlayer connection, low-permeability ceramic green sheets 12 for external layers provided with via-holes 8 for extraction, high-permeability ceramic green sheets 13 for internal layers provided with coil conductive patterns 5 and via-holes 6 for interlayer connection, and high-permeability ceramic green sheets 13 for external layers provided with via-holes 8 for extraction.

The high-permeability ceramic green sheet 13 is produced as follows. Starting materials of oxides of nickel, zinc, and copper are mixed and calcined at 800°C for one hour. The calcined mixture is pulverized with a ball mill, followed by drying. Thereby, an Ni-Zn-Cu ferrite starting material (mixed oxide powder) with an average particle size of about 2 μm is obtained.

Subsequently, a solvent, a binder, and a dispersant are

added to the ferrite starting material, and mixing is performed to form a slurry. Subsequently, using the ferrite starting material in the form of slurry, a high-permeability ceramic green sheet 13 with a thickness of 40 μm is formed by a doctor blade process or the like.

On the other hand, the low-permeability ceramic green sheet 12 is produced as follows. Starting materials of oxides of nickel, zinc, and copper are mixed and calcined at 800°C for one hour. The calcined mixture is pulverized with a ball mill, followed by drying. Thereby, an Ni-Zn-Cu ferrite starting material (mixed oxide powder) with an average particle size of about 2 μm is obtained.

Subsequently, a spherical evaporative pore-forming agent composed of a commercially available spherical polymer, for example, spherical crosslinked polystyrene with an average particle size of 8 μm, is added to the ferrite starting material, and a solvent, a binder, and a dispersant are further added thereto, followed by mixing to form a slurry. In the first embodiment, as the evaporative pore-forming agent, TECHPOLYMER (trade name) manufactured by Sekisui Plastics Co., Ltd. is added to the ferrite starting material so as to achieve a porosity of 60%. Subsequently, using the ferrite starting material in the form of slurry, a low-permeability ceramic green sheet 12 with a thickness of 40 μm is formed by a doctor blade process or the like. The

evaporative pore-forming agent is burned off during firing in the post process, and thereby pores are formed.

The coil conductive pattern 5 is composed of Ag, Pd, Cu, Au, or an alloy of these metals, and is formed by screen printing or the like. In order to form the via-hole 6 for interlayer connection or the via-hole 8 for extraction, a hole for the via-hole is opened using a laser beam or the like, and the hole is filled with a conductive paste composed of Ag, Pd, Cu, Au, or an alloy of these metals.

The coil conductive patterns 5 are electrically connected in series through via-holes 6 for interlayer connection to form a spiral coil L. Both ends of the spiral coil L are electrically connected to the via holes 8 for extraction.

The individual sheets 12 and 13 are stacked and press-bonded to produce a rectangular parallelepiped ceramic laminate 20 as shown in Fig. 2. The ceramic laminate 20 is subjected to heat treatment (binder removal treatment) at 400°C for 3 hours, and firing is then performed at 915°C for 2 hours. A sintered ceramic laminate 20 is thereby obtained.

As a result, in a low-permeability coil portion 15 formed by stacking the low-permeability ceramic green sheets 12, a first coil La comprising coil conductive patterns 5 which are electrically connected in series and many pores 32 (refer to Fig. 3) are formed. The average size of the pores

32 is 5 to 20 μm, and preferably, the pore content by volume (porosity) in the low-permeability coil portion 15 is 30% to 80%. The porosity of the low-permeability coil portion 15 is calculated according to the following formula, provided that the specific gravity of the pore (air) is 0 g/cm³:

Porosity of low-permeability coil portion 15

$= \{1 - (W/V)/G\} \times 100(\%)$

W: Total weight of ceramic sheets 12 only of low-permeability coil portion 15 (after firing)

V: Volume of ceramic sheets 12 only of low-permeability coil portion 15 (after firing)

G: Theoretical density of ferrite starting material

If the porosity is less than 30%, the dielectric constant increases, and it is not possible to decrease the dielectric constant sufficiently. If the porosity exceeds 80%, the mechanical strength of the low-permeability coil portion 15 after firing is decreased, and it becomes difficult to subsequently perform resin impregnation, etc., which is undesirable.

On the other hand, in a high-permeability coil portion 16 formed by stacking the high-permeability ceramic green sheets 13, a second coil Lb comprising coil conductive patterns 5 which are electrically connected in series and a small number of pores are formed. The second coil Lb and the first coil La are electrically connected in series to

form a spiral coil L. The pores are generated by air bubbles included when the ferrite starting material in the form of slurry is prepared and the volatile components of the binder and the dispersant. However, the number of pores formed in the high-permeability coil portion 16 is small, and the porosity is 10% or less. The porosity of the high-permeability coil portion 16 is calculated according to the following formula:

Porosity of high-permeability coil portion 16

$= \{1 - (W1/V1)/G\} \times 100(\%)$

W1: Total weight of ceramic sheets 13 of high-permeability coil portion 16 (after firing)

V1: Volume of ceramic sheets 13 of high-permeability coil portion 16 (after firing)

G: Theoretical density of ferrite starting material

Additionally, the pores formed in the low-permeability coil portion 15 and the high-permeability coil portion 16 include open pores and closed pores. The high-permeability coil portion 16 must have a high permeability relative to the low-permeability coil portion 15. Depending on the specification of the monolithic inductor 1, an evaporative pore-forming agent may be added to the ceramic green sheet 13 of the high-permeability coil portion 16.

Next, external electrodes 21 and 22 are formed on both end faces of the sintered ceramic laminate 20. The external

electrodes 21 and 22 are electrically connected to the spiral coil L through the via-holes 8 for extraction. Folded portions of each of the external electrodes 21 and 22 extend over four side faces. The external electrodes 21 and 22 are formed by coating, baking, or the like.

Next, the sintered ceramic laminate 20 is immersed in an epoxy resin with a dielectric constant of 3.4 (alternatively, in a water-soluble glass) so that the pores are filled with the epoxy resin and an epoxy resin film is formed on the surface of the sintered ceramic laminate 20. Subsequently, the epoxy resin is cured at 150°C to 180°C (for 2 hours). Since the baking temperature for the external electrodes 21 and 22 is high at about 850°C, preferably the external electrodes 21 and 22 are formed before the impregnation of the resin.

Fig. 3 is an enlarged cross-sectional view showing a part of the low-permeability coil portion 15 of the sintered ceramic laminate 20. A plurality of pores 32 are formed in the sintered ceramic laminate 20. The pores 32 are filled with an epoxy resin 33, and the surface of the sintered ceramic laminate 20 is also covered with the epoxy resin 33. About 30% to 70% by volume of the pores 32 is filled with the resin 33. Namely, the pores 32 may be entirely filled with the resin 33, or the pores 32 may be partially filled with the resin 33, and in such a case, a pore 34 is further

formed in the pore 33 partially filled with the resin 33.

Next, the sintered ceramic laminate 20 which has been impregnated with the resin is subjected to barrel grinding so that the metal surfaces of the external electrodes 21 and 22 are more securely exposed, and plating layers are formed on the surfaces of the external electrodes 21 and 22 by nickel plating and tin plating. A monolithic inductor 1 shown in Fig. 4 is thus obtained.

In the monolithic inductor 1 having the structure described above, the coil portion 16 composed of the ferrite ceramic having a small number of pores has a high permeability, and the coil portion 15 composed of the ferrite ceramic having a large number of pores has a low permeability. In the first embodiment, the high-permeability coil portion 16 has an initial permeability of 430, and the low-permeability coil portion 15 has an initial permeability of 133.

Furthermore, in the coil portion 16 composed of the ferrite ceramic having a small number of pores, the permeability and the dielectric constant are high, and in the coil portion 15 composed of the ferrite ceramic having a large number of pores, the permeability and the dielectric constant are low. Consequently, the inductance of the first coil La in the coil portion 15 is lower than the inductance of the second coil Lb in the coil portion 16. The stray

capacitance Ca formed in parallel with the first coil La in the coil portion 15 is smaller than the stray capacitance Cb formed in parallel with the second coil Lb in the coil portion 16. Consequently, the resonant frequency, i.e., Fa $= 1/2p(LaCa)^{1/2}$, of an LC parallel resonant circuit containing the first coil La and the stray capacitance Ca is higher than the resonant frequency, i.e., Fb $= 1/2p(LbCb)^{1/2}$, of an LC parallel resonant circuit containing the second coil Lb and the stray capacitance Cb. As a result, a monolithic inductor 1 having high impedance in the wide range can be obtained.

Fig. 5 is a graph which shows the impedance characteristics of the monolithic inductor 1. In Fig. 5, the solid line 41 indicates the impedance characteristics of the low-permeability coil portion 15, the solid line 42 indicates the impedance characteristics of the high-permeability coil portion 16, and the solid line 43 indicates the resultant impedance characteristics of both.

As is evident from the graph, it is possible to obtain a monolithic inductor 1 in which a noise reduction effect is achieved over a wide range of high impedances.

Since the same ferrite material is used for the ferrite ceramic materials, bonding strength at the bonding interface between the low-permeability coil portion 15 and the high-permeability coil portion 16 is stronger compared with the

conventional monolithic inductor including a nonmagnetic intermediate layer. Furthermore, since the shrinkage rate of the low-permeability coil portion 15 is substantially equal to the shrinkage rate of the high-permeability coil portion 16 during firing, satisfactory bonding is easily obtained. Moreover, there is no risk that the magnetic properties of the coil portions 15 and 16 are degraded due to interdiffusion between the ferrite ceramic materials of the low-permeability coil portion 15 and the high-permeability coil portion 16.

The monolithic inductor 1 is a horizontal winding type inductor in which the stacking direction of the ceramic green sheets 12 and 13 is parallel to the mounting surface of the ceramic laminate 20 and perpendicular to the external electrodes 21 and 22. The coil portions 15 and 16 having different dielectric constants are disposed in series between the external electrodes 21 and 22, and stray capacitances Ca and Cb are mainly generated between the opposing external electrodes 21 and 22. In the first embodiment, the ratio of the dielectric constant of the coil portion 15 composed of the ferrite ceramic having a large number of pores to the dielectric constant of the coil portion 16 composed of the ferrite ceramic having a small number of pores is about 1/10. Since the coil portions 15 and 16 are arranged in series, the stray capacitance of the

entire monolithic inductor 1 is reduced, and high-frequency characteristics are improved.

Furthermore, if necessary, the winding directions of the first coil La and the second coil Lb which are respectively contained in the coil portions 15 and 16 may be reversed. Thereby, magnetic coupling between the first coil La and the second coil Lb is suppressed, and a high-frequency noise elimination effect by the first coil La of the low-permeability coil portion 15 and a low-frequency noise elimination effect by the second coil Lb of the high-permeability coil portion 16 are independently exhibited, thus enabling production of a monolithic inductor 1 having a further improved noise elimination effect.

(Second Embodiment)

A second embodiment is a monolithic inductor having the same structure as that of the first embodiment. The high-permeability ceramic green sheet and the low-permeability ceramic green sheet are formed as in the first embodiment using the same materials and by the same process except that a pore-forming agent is incorporated into the ferrite material when the high-permeability ceramic green sheet is formed, and the high-permeability coil portion has a porosity of 20%. The low-permeability ceramic green sheet is formed as in the first embodiment, and the low-permeability coil portion has a porosity of 60%.

According to the second embodiment, the same advantage as that of the first embodiment is obtained, and since the pore-forming agent is incorporated into both the high-permeability coil portion and the low-permeability coil portion, the shrinkage rates during firing of the two coil portions are close to each other, and the bonding strength therebetween is larger than that of the first embodiment. Furthermore, since the high-permeability coil portion is impregnated with the resin, the strength of the laminate is also increased.

(Third Embodiment, Figs. 6 and 7)

As shown in Fig. 6, a monolithic LC filter 51 includes coil portions 65 and 66 and a capacitor portion 67 interposed between the coil portions 65 and 66. Each of the coil portions 65 and 66 comprises ceramic green sheets 62 provided with coil conductive patterns 55 and via-holes 56 for interlayer connection, and ceramic green sheets 62 provided with via-holes 58 for extraction. The capacitor portion 67 comprises ceramic green sheets 63 provided with capacitor conductors 59 and via-holes 56 for interlayer connection and ceramic green sheets 63 provided with capacitor conductors 60 and via-holes 56 for interlayer connection.

The ceramic green sheet 63 is prepared as in the ceramic green sheet 13 in the first embodiment, and a

detailed description thereof will be omitted. On the other hand, the ceramic green sheet 62 is prepared as in the ceramic green sheet 12 in the first embodiment except that a pore-forming agent is incorporated into the ferrite starting material so that the porosity is 80%, and a detailed description thereof will be omitted.

The individual sheets 62 and 63 are stacked and press-bonded, and firing is performed. Thereby, a rectangular parallelepiped sintered ceramic laminate 70 as shown in Fig. 7 is produced. In the coil portions 65 and 66 formed by stacking the ceramic green sheets 62, coils L1 and L2, each comprising conductive patterns 55 which are electrically connected in series, and many pores are formed.

On the other hand, in the capacitor portion 67 formed by stacking the ceramic green sheets 63, a capacitor C comprising the opposing capacitor electrodes 59 and 60, and a small number of pores are formed. The capacitor C and the coils L1 and L2 are electrically connected to form a T-type LC filter.

Next, external electrodes 71, 72, and 73 are formed on both end faces and a center of the sintered ceramic laminate 70. The external electrodes 71 and 72 are electrically connected to the spiral coils L1 and L2 through the via-holes 58 for extraction, respectively.

Next, the sintered ceramic laminate 70 is immersed in

an epoxy resin with a dielectric constant of 3.4 (alternatively, in a water-soluble glass) so as to be impregnated with the resin. The sintered ceramic laminate 70 which has been impregnated with the resin is subjected to barrel grinding, and then plating layers are formed on the surfaces of the external electrodes 71 to 73. A monolithic LC filter 51 is thereby produced.

In the monolithic LC filter 51 having the structure described above, the capacitor portion 67 composed of the ferrite ceramic having a small number of pores has a high dielectric constant and a high permeability, and the coil portions 65 and 66 composed of the ferrite ceramic having a large number of pores have a low dielectric constant and a low permeability. In the third embodiment, the capacitor portion 67 has an initial permeability of 430 and a dielectric constant of 14.5. The coil portions 65 and 66 each have an initial permeability of 65 and a dielectric constant of 4.0.

Consequently, the dielectric constant of the coil portions 65 and 66 can be decreased, and the stray capacitance formed in parallel with each of the coils L1 and L2 can be reduced. As a result, a monolithic LC filter 51 having satisfactory high-frequency characteristics can be obtained. As described above, by forming pores in the coil portions 65 and 66 so that the dielectric constant of the

coil portions 65 and 66 is decreased, it is possible to produce, using the same ferrite ceramic material, a monolithic LC filter 51 which is less influenced by stray capacitance.

Although the third embodiment is designed such that the coil portions 65 and 66 have a large number of pores, depending on the specification of the monolithic LC filter 51, the capacitor portion 67 may have a large number of pores.

(Other Embodiments)

It is to be understood that the present invention is not limited to the embodiments described above, and within the scope not deviating from the spirit of the present invention, various alterations can be made.

For example, a monolithic ceramic electronic component of the present invention may include three or more element portions having different porosities. Examples of the monolithic ceramic electronic component include monolithic impedance components, monolithic LC filters, monolithic capacitors, and monolithic transformers in addition to monolithic inductors. A monolithic capacitor includes a first element portion and a second element portion, the first element portion being formed by stacking dielectric ceramic layers having a high porosity (i.e., dielectric ceramic layers having a low dielectric constant), the second

element portion being formed by stacking dielectric ceramic layers having a low porosity (i.e., dielectric ceramic layers having a high dielectric constant). Furthermore, as the ceramic material, various functional ceramic materials, such as magnetic ceramic materials, dielectric ceramic materials, semiconductor ceramic materials, and piezoelectric ceramic materials, may be used.

In the embodiments, examples of single products have been described. In the case of mass production, of course, production may be performed using a mother lamination block containing a plurality of monolithic inductors.

Furthermore, when a monolithic ceramic electronic component is fabricated, after the ceramic sheets provided with conductive patterns and via-holes are stacked, the method for integrally firing the stacked ceramic sheets is not particularly limited. The ceramic sheets to be used may be preliminarily fired. Alternatively, a monolithic ceramic electronic component may be produced by the method described below. Namely, a ceramic layer is formed by coating of a ceramic material in the form of paste by printing or the like, and then a conductive material in the form of paste is applied onto the ceramic layer to form a conductive pattern and a via-hole. Furthermore, the ceramic material in the form of paste is applied thereon to form a ceramic layer. By repeating coating in sequence in such a manner, a ceramic

electronic component having a lamination structure can be obtained.

Industrial Applicability

As described above, the present invention is useful in monolithic ceramic electronic components, such as LC composite components, and is excellent in that element portions having different dielectric constants and different permeabilities can be bonded to each other with required strength without providing an intermediate layer.